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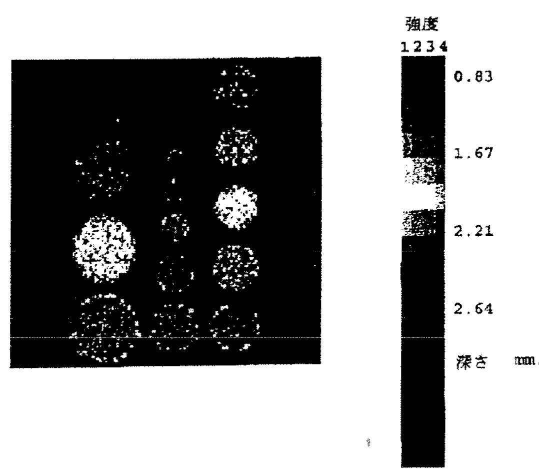
(54)【発明の名称】　対象物内のきずの検出方法及び位置決め装置並びにディスプレイ

(57)【要約】

【課題】　複雑な形状寸法と不均一な被加熱表面に使用して対象物内のきずの位置決めと大きさの測定を正確に行うことができ、自動化でき且つ客観的な方法を提供する。

【解決手段】　対象物内のきずの位置決めをするシステムは、対象物の表面を加熱するヒータと、加熱された表面上の各々の画素の強度を記録するレコーダと、画素の強度から画素のコントラストを決定する手段と、画素のコントラストに基づいて対象物内のきずの大きさと位置を決定する手段とからなり、連続的なサーマルイメージについて各画素のコントラストを監視し、これらの画素のコントラストを利用して対象物内のきずの位置を決定する。対象物の表面とその下にあるきずは、特定の色を有するきずの深さと相互に関連するカラースペクトルのイメージプリント上に描かれる。



【特許請求の範囲】
【請求項１】　解像要素の配列に分割された表面を有する対象物内のきずの検出方法において、
対象物の表面を加熱する工程と、加熱された前記表面上の画素に対応する各解像要素の複数のサーマルイメージを所定時間にわたって記録する工程と、前記サーマルイメージの各々における前記画素の各々の画素について個々の画素の強度を決定する工程と、各サーマルイメージについて平均画素強度を決定する工程と、前記個々の画素の強度から前記平均画素強度を差し引くことによって前記サーマルイメージの各々における前記画素の各々についての画素のコントラストを得る工程と、前記画素のコントラストに基づいて前記対象物内のきずの深さを決定する工程とを有する方法。
【請求項２】　前記画素のコントラストを使用し、その画素コントラストのピークを得て、以下の式
【数１】$l=\sqrt{(\kappa \tau_{peak} / 3)}$
ただし、τ_{peak} はピーク時間、l はきずの深さ、κ は対象物の熱拡散率を使用してきずの位置を決定することにより、きずの深さを決定することを特徴とする、請求項１に記載の方法。
【請求項３】　前記画素のコントラストの時間微分を計算して、微分コントラストのピークを得ることによってきずの深さを決定することを特徴とする、請求項１に記載の方法。
【請求項４】　以下の式
【数２】$l=(\pi / 2)\sqrt{(\kappa \tau_c)}$
ただし、τ_c は固有時定数、l はきずの深さ、κ は対象物の熱拡散率を使用してきずの深さを決定することを特徴とする、請求項３に記載の方法。
【請求項５】　以下の式
【数３】$l=\pi\sqrt{(\kappa \tau_c)}$
ただし、τ_c は固有時定数、l はきずの深さ、κ は対象物の熱拡散率を使用してきずの深さを決定することを特徴とする、請求項３に記載の方法。
【請求項６】　カラースペクトルを使用してきずの深さと横方向の位置を表示する対象物のイメージプリントを生成する工程を含むことを特徴とする、請求項１に記載の方法。
【請求項７】　画素の配列として視覚化できる表面を有する対象物内のきずの位置決めをする装置において、
対象物の表面を加熱するヒータと、画素の強度を記録するレコーダと、前記画素の強度から画素のコントラストを決定する手段と、前記画素のコントラストに基づいて前記対象物内のきずの深さと位置を決定する手段とからなる装置。
【請求項８】　前記ヒータは、フラッシュランプ、石英水銀灯、マイクロ波装置またはレーザーであることを特徴とする、請求項７に記載の装置。
【請求項９】　以下の式
【数４】$l=\sqrt{(\kappa \tau_{peak} / 3)}$
ただし、τ_{peak} はピーク時間、l はきずの深さ、κ は対象物の熱拡散率を使用して前記画素のコントラストから各々のきずの深さを決定することを特徴とする、請求項７に記載の装置。
【請求項１０】　以下の式
【数５】$l=(\pi / 2)\sqrt{(\kappa \tau_c)}$
ただし、τ_c は固有時定数、l はきずの深さ、κ は対象物の熱拡散率を使用して前記画素のコントラストの導関数から各々のきずの深さを決定することを特徴とする、請求項７に記載の装置。
【請求項１１】　以下の式
【数６】$l=\pi\sqrt{(\kappa \tau_c)}$
ただし、τ_c は固有時定数、l はきずの深さ、κ は対象物の熱拡散率を使用して前記画素のコントラストの導関数から各々のきずの深さを決定することを特徴とする、請求項７に記載の方法。
【請求項１２】　カラースペクトルを使用してきずの深さと横方向の位置を表示するイメージプリントを生成する手段を含むことを特徴とする、請求項７に記載の装置。
【請求項１３】　複数の解像要素によって示される表面を有する対象物のきずのディスプレイにおいて、深さと相互に関連するカラースペクトルと、前記対象物の表面の各々の解像要素の下のきずの深さを決定する手段と、きずの深さと相互に関連する色によって描かれるきずを有する対象物の表面を表示する手段とからなる、対象物のきずのディスプレイ。
【請求項１４】　イメージプリント上のきずを表示する手段と含むことを特徴とする、請求項１３に記載のディスプレイ。
【発明の詳細な説明】
【０００１】
【発明の属する技術分野】本発明は、非破壊試験に関し、特に非定常サーモグラフィ（過渡サーモグラフィ）を利用して表面下のきず（欠陥）の深さと横方向の位置を決定する対象物の非破壊試験およびこれらのきずを表示する画像技術に関する。
【０００２】
【従来の技術】対象物内のきずの存在は、所定時間に対象物を通る熱の伝達に依存する非定常サーモグラフィを含む種々の技術によって決定できる。非定常サーモグラフィ法は、表面を加熱中に赤外線カメラを使用して一連の画像配列のデータを捕捉することによって各解像要素（分解要素）の温度上昇を記録し、この温度上昇を分析して、加熱時間の平方根に対して線形の温度上昇への遷移が起こるか否かを識別することからなる。この線形の温度上昇は、対象物内のきずの存在を示している。この決定は、現状のままでは困難であり、複雑な形状寸法および不均一な加熱によってさらに困難になる。

【０００３】従来の非定常サーモグラフィは、時間の関数としての対象物の予め加熱した表面の個々の赤外画像「スナップショット」を分析することからなる。表面下のきずは、熱がそのきずによって分散できないためにより強い強度の赤外線を放射する画像内の「ホットスポット」によって識別される。この従来のプロセスの問題の一つは、非定常サーモグラフィの分析では一つのスナップショットをちょうどよい時に選択することである。分析のためにどのスナップショットを選択するかが重要であり、最良の選択はきずの深さや大きさのように制御不能で未知の多くの要素に基づいている。誤ったスナップショットが選択されると、前のスナップショット又はその後のスナップショットに示されるきずを検出することができない。

【０００４】スナップショットの使用を避けるためには、検査員が記録された画像のビデオ再生を見て、きずを示す明るいスポットを視覚的に識別する。この方法の問題は、容易に自動化できず、オペレータへの依存が高く、複雑な形状寸法又は不均一な被加熱面に容易に応用できず、また、この方法できずを検出できてもそのきずの実際の深さと横方向の位置（以下「位置」という）又は大きさを正確に決定することができないことである。

【０００５】従来では、対象物の超音波探傷試験によってきずの位置決めをしていた。実質的に表面から侵入して対象物内のきずによって反射する超音波が対象物に当てられる。反射波を受けるのに必要な時間に基づいてきずの位置を決定することができる。

【０００６】

【発明が解決しようとする課題】超音波探傷試験は、必要とされる密接な音波の接触によって、表面全体にわたってトランスデューサを機械走査させている。密接な音波の接触を可能にするために、液体の触媒物質の流れ又は対象物の全液浸を使用しなければならないが、これは実質的な理由によって許容できないことが多い。プロセスの問題に加えて、この技術は大きい対象物や複雑な対象物を試験するためには役に立たない。典型的には、数平方メートルの機械走査を行うためには数時間かかる。また、幾何学的に複雑な部品のための走査システムは複雑で高価である。

【０００７】この技術で必要なことは、複雑な形状寸法と不均一な被加熱表面に使用して対象物内のきずの位置決めと大きさの測定を正確に行うことができ、自動化され、客観的な非定常サーモグラフィ深さ画像技術である。

【０００８】

【課題を解決するための手段】本発明は、対象物内のきずの位置決めをする非破壊試験技術およびその装置に関する。この装置は、対象物の表面を加熱するヒータと、加熱された表面の各画素の強度を記録するレコーダと、表面の強度から画素のコントラストを決定する手段と、画素のコントラストに基づいて対象物内のきずの大きさと位置を決定する手段とからなる。

【０００９】この方法は、対象物の表面を加熱する工程と、所定時間にわたって表面の各解像要素の連続的なサーマルイメージを記録する工程と、そのサーマルイメージの平均画素強度を決定して個々の画素の強度から平均画素強度を差し引くことによって表面の各々の連続的なサーマルイメージについての各解像要素（画素）のコントラストを決定する工程と、画素のコントラストに基づいて対象物内のきずの位置を決定する工程とからなる。

【００１０】

【発明の実施の形態】本発明は、非定常サーモグラフィ分析技術を使用して対象物内のきずの大きさと位置を決定する自動非破壊試験法に関する。この方法は、時間に対する被加熱物の表面温度の変化を監視することによって対象物内のきずを客観的に検出するために時間－温度データを使用する方法であり、対象物の表面を加熱し、対象物の表面の各画素についての熱時定数を監視することからなる。本願明細書において、画素とは画像配列中の矩形の画像素子であり、解像要素とは、一つの画素に対応する対象物の表面の矩形の領域である。

【００１１】対象物の表面を加熱するために使用される装置は、サーモグラフィ監視を可能にするためにその表面を十分な温度に加熱することができるものである。典型的には、薄い対象物、例えば、約０．１２５インチ（０．５７ｍｍ）以下の厚さの対象物は、約5℃以下の温度で、できる限り約1℃程度の低い温度の最小の加熱を必要とするだけである。一方、厚い対象物は、かなり高い温度の加熱を必要とし、例えば、０．５インチの厚い対象物では約２０℃の加熱を必要とする。対象物を加熱する程度の決定には色と放射率を含む表面の要素も重要であり、物理的性質により対象物やその表面を損傷しない温度の加熱上限が規定される。

【００１２】きずの位置と大きさを正確に決定するためには、対象物の表面を十分に短い時間で所望の温度まで加熱して、対象物の残りの部分が加熱されないようにしなければならない。典型的には、加熱は、薄い材料では１秒の何分の１で起こるが、より厚い又は大きい材料ではフラッシュで数分間かかる。対象物に熱が侵入すると、対象物の表面付近の探傷精度が低下する。例えば、厚さ０．１２５インチの黒鉛繊維とポリマーの複合品は、フラッシュランプからの４メガワットの熱パルスにより数ミリ秒間で加熱できるが、厚さ０．５インチの対象物は、石英水銀灯からの２キロワットの熱パルスにより数秒間ないし数分間加熱しなければならない。他の可能な加熱方法としては、マイクロ波、レーザー、高温かつ高速の加熱が可能な他の従来の加熱手段など使用がある。

【００１３】対象物の表面が加熱されると、赤外線ビデオカメラが、対象物の表面の連続的なサーマルイメージ

を記録および記憶し、その各画素を記録する。記録される画像の数は、その結果生ずるサーマルイメージの所望の解像度、カメラの速度、および特定の対象物の時定数に依存する（以下を参照）。約１０個の画像を使用して一つのサーマルイメージを形成することができるが、典型的には約２５個の画像により十分な解像度を提供することができ、約１００個の画像によりサーマルイメージの良好な解像度を提供することができる。一般に現在のビデオ技術では約５００個以下の画像を得ることができ、約２５個以上の画像が好ましい。

【００１４】対象物の同じ側に加熱装置とビデオカメラを配置する場合には、サーマルイメージを得るための時間を規定するために使用される時定数τ_cは式４から得られる。ここで、深さとは対象物の厚さである。

【００１５】

【数７】$\tau_c = 4 l^2 / (\pi^2 \kappa)$　　…（１）

ただし、τ_c＝「固有」時定数

κ＝対象物の熱拡散率

l＝深さ

カメラとヒータを対象物の反対側に配置した場合には、（１）式から係数４を省略する。約５の固有時定数の後に対象物内が熱平衡に達っするので、サーマルイメージを得るために使用される時間は、典型的に約３乃至約５の時定数τ_c又はそれ以上の時定数と等しい。

【００１６】ビデオ装置は、少なくとも約６０フレーム／秒から約２５０フレーム／秒以下又はそれ以上のフレーム率で、少なくとも約０．０１℃乃至約０．０２℃のカメラ温度感度の高速焦点面アレイカメラ又は同様の装置が好ましい。最小許容解像度は、最終的なイメージプリントの所望の解解像度に依存し、典型的には１２８×１２８以上の画素の解像度が好ましい。

【００１７】その画像（ちょうと良いときのポイント）の平均画素強度（ｂ）をそのちょうど良いときのポイントにおける個々の画素の強度（ａ）を差し引くことによって各画素のコントラストを決定するために記憶されたサーマルイメージを使用する。次に、各画素についてこのコントラストを時間に対してプロットする（図２参照）。きずの部分のコントラストは、その画像がビデオカメラによって得られたときに画像数がピークに達する。ピークになるときがあれば、きずの深さを決定することができ、深さの近似値は（２）式によって得られる。

【００１８】

【数８】$l = \sqrt{(\kappa \tau_{peak} / 3)}$　　…（２）

ただし、l＝深さ

τ ＝「固有」時定数

κ＝cgs単位cm^2/secで測定した媒体の「熱拡散率」

（２）式は、きずの厚さにより熱がきずの回りを流れない「貫通熱」のきずである場合に特に有用である（図３Ｂの「側方熱」のきずに対する図３Ａの「貫通熱」のきずを参照）。

【００１９】しかし、きずの回りの熱の拡散速度が、きずを貫通する熱の拡散速度よりも速い場合（図３Ｂ）、画素のコントラストのグラフには、コントラストのピークが明瞭には出現しない（図４）。従って、微分コントラストのピークを決定するために、コントラスト曲線を時間で微分する。「側方熱」のきずの深さは、以下の式６を使用してピークの時間から決定することができる。

【００２０】

【数９】$l = 0.524 \pi \sqrt{(\kappa \tau_i)}$

$\tau_c = 1.10 \tau_i$

ただし、l＝深さ

τ_c＝「固有」時定数

τ_i＝微分ピークの変曲時間

κ＝cgs単位cm^2/secで測定した媒体の「熱拡散率」

実施例

本発明の精度は、注意深く配置した一連の平坦なきずを有する対象物を使用して規定した。図６、６Ａ、６Ｂおよび６Ｃに示すように、きず１、２、３、４および５は、同じ直径22mmを有し、それぞれ1.3mm、1.6mm、1.9mm、2.2mmおよび2.5mmと深さが異なっている。きず６、７、８、９、１０および１１は、同じ深さ1.3mmを有し、それぞれ22mm、16.5mm、11mm、8.25mm、5.5mmおよび2.75mmの異なる直径を有する。きず１２、１３および１４は、同じ直径33mmを有し、それぞれ1.3mm、1.9mmおよび2.5mmと深さが異なっている。

【００２１】テストパラメータは次の通りである。（１）各画像フレームは、Ｎが２５６の場合の（対象物の表面の解像要素に対応する）Ｎ×Ｎ画素からなり、（２）典型的にＮ＝１２８について１乃至４００、Ｎ＝２５６について１乃至２００の範囲の画像フレームの数Ｚは１００であり、（３）各画素は、記憶装置の２バイトを占有し、熱放射強度を示す０から４０９５までの１２ビット数で示されるものであった。

【００２２】フラッシュランプからの４メガワットの熱パルスによって対象物を約5℃で0.010秒間加熱した。加熱後、約２５秒間操作して２５６×２５６の画素の解像度を有する高速焦点面アレイカメラを使用して、各解像要素の強度を記録し、各画素を１２ビットで示した。ユーザーのパラメータを決定し、システムに入れた。そのシステムは、分析に使用するための始動フレーム数（表面が加熱される前にとられたフレームは省略した）と、スケルチ定数と、雑音抑圧（コントラスト曲線のピークから開始値又は最終値を引いたものの絶対値がこの定数より小さい画素の位置を捨てる）と、視界（赤外線カメラから対象物までの距離であり、スケーリングを許容し、従って正確な大きさの決定を許容する）とを含む。各画素のコントラストは、画素と画素の平均値の固定コントラストゲイン倍の差を使用して、画像全体の平均画素強度について決定した。この操作は、一組のコン

トラスト曲線を生成する各画像フレームの各画素について行った。次に、６点差法を使用して、各コントラスト曲線の導関数を決定した。各微分コントラスト曲線のピークを生成する画像フレーム数を保管又は低いコントラスト又はノイズを示す画素の位置についてのこの情報を抑制することによって、微分コントラストのピークの情報を記憶した。次に、微分コントラストのピークが生ずる画像フレームの位置を使用してきずの深さを決定した。これらのきずの深さは、図7に示すような強度カラースペクトルを使用して視覚的に示した。図７、図８および図９に示すきずの番号は、図７、図８および図９で検出したきずを示す図６の番号と一致している。

【００２３】きずのイメージプリントは、各画素について記憶されたピークフレーム数を図７、図８および図９の右側に示す１６色パレット内の色の一つに割り当てることによって生成した。これは、色の総数（１６）をフレーム総数（１００）で割り、所定の画素についてのピークフレーム数を掛けることによって行った。次に、この数を整数の指数に丸めて、この画素を表示することができる１６色の一つを選択する色パレットに入れた。このプロセスを、画像の全ての画素位置について繰り返した。図７、図８および図９の色パレットの左から右に示される各々の色の４つの強度レベルを使用してこの画像をさらに良好なものにした。最大ピークは所定の色の最高強度（レベル１）に対応し、最小ピークは所定の色の最低強度（レベル４）に対応する(図７、図８および図９を参照)。

【００２４】対照的に、図8は、強度のプロファイルのスナップショットに依存する従来の画像技術を示す本発明によるイメージプリントを示している。この図８から明らかなように、すべてのきずが明らかであるので、ちょうど良いときに良好なポイントで「スナップショット」がとられた。しかし、大部分のきずが同じ深さに配置するように見える。従って、いずれのきずについても正確な深さを決定することができない。さらに、きず１１はわずかに見えるにすぎず、一つのきずとして特定することが困難である。

【００２５】また、図9は、従来の非定常サーモグラフィを使用するイメージプリントであり、同様に混乱する情報を提供している。この図では、きずの縁部がきずの中心部より浅くなっているように見える。従って、きずは平坦であるにもかかわらず凹面のように見える。また、きずの深さを正確に決定することができない。

【００２６】本発明は、従来の非破壊試験と比べて多数の利点を提供する。即ち、人的エラーを実質的に除去し、きずの位置決め能力を提供し、画像を単純化する。従来のプロセスは、多数の画像を見るオペレータに依存するか、表面の単一の「スナップショット」、即ち、人的エラーに依存し、単にきずの存在を検出していたにすぎない。本発明では、きずの深さと大きさを正確に決定できるが、従来の方法では、深さを正確に検出することができない。

【００２７】以上説明したように、本発明によれば、複雑な形状寸法と不均一な被加熱表面に使用して対象物内のきずの位置決めと大きさの測定を正確に行うことができ、自動化でき且つ客観的な方法が提供される。

【００２８】また、対象物内のきずの位置決めをする本発明にかかるシステムは、対象物の表面を加熱するヒータと、加熱された表面上の各々の画素の強度を記録するレコーダと、画素の強度から画素のコントラストを決定する手段と、画素のコントラストに基づいて対象物内のきずの大きさと位置を決定する手段とからなり、連続的なサーマルイメージについて各画素のコントラストを監視し、これらの画素のコントラストを利用して対象物内のきずの位置を決定する。対象物の表面とその下にあるきずは、特定の色を有するきずの深さと相互に関連するカラースペクトルのイメージプリント上に描かれる。

【図面の簡単な説明】

【図１】平均画素強度（ｂ）に対する個々の画素（ａ）についての時間に対する強度（温度）を示すグラフである。

【図２】図１の画素についての時間に対する画素のコントラストを示すグラフであり、コントラストのピークを示している。

【図３】図３（Ａ）は、貫通熱の流れを許容する「貫通熱のきず」の例である薄い層剥離を示す対象物の断面図であり、図３（Ｂ）は、主として横方向の熱の流れを必要とする「側方熱のきず」の例である厚い層剥離を示す対象物の断面図である。

【図４】「側方熱のきず」のためにコントラストのピークがない個々の画素についての時間に対する画素のコントラストを示すグラフである。

【図５】図４から「側方熱のきず」の微分コントラストのピークを示すために個々の画素について時間に対する微分画素コントラストを示すグラフである。

【図６】図６（Ｏ）、図６（Ａ）、図６（Ｂ）および図６（Ｃ）は、図７、図８および図９に示される試験片とそのきずの相対的な大きさを示す図である。

【図７】本発明のサーモグラフィ技術を使用して画素の強度を示すイメージプリントの説明図である。

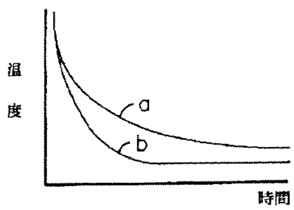
【図８】従来の画像技術を使用して画素の強度を示す本発明のイメージプリントの説明図である。

【図９】従来の非定常サーモグラフィを使用して温度を示す画素の強度を示す本発明のイメージプリントの説明図である。

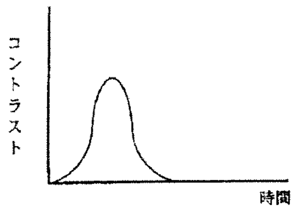
【符号の説明】

１～１４…きず

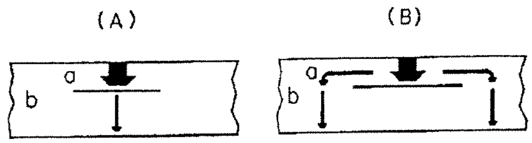
【図１】



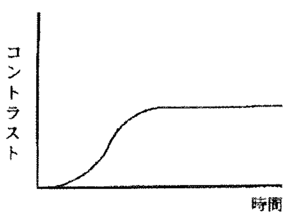
【図２】



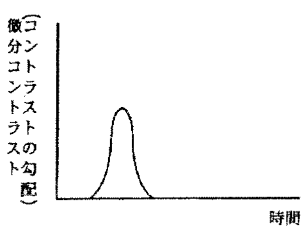
【図３】



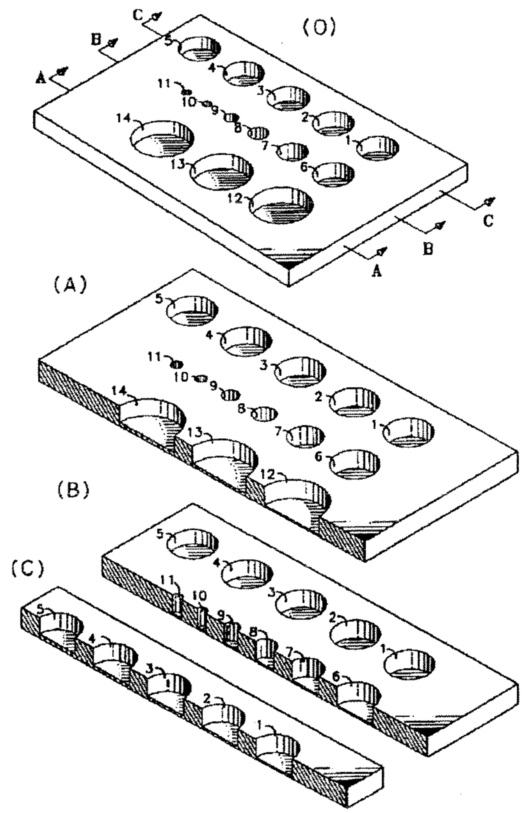
【図４】



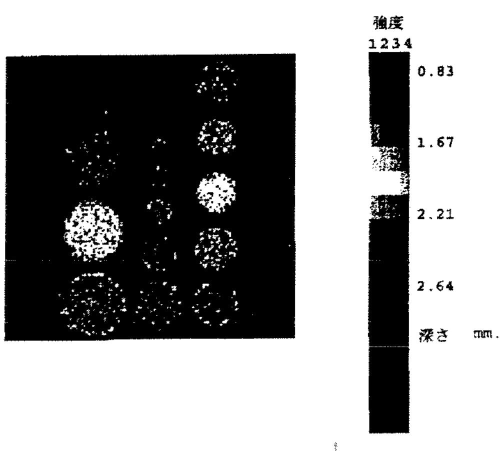
【図５】



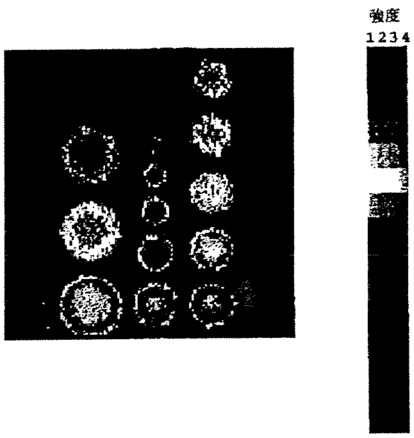
【図６】



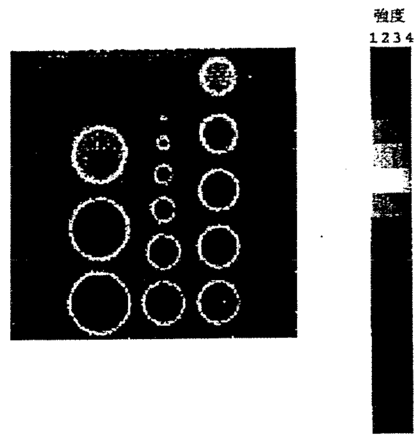
【図７】



【図８】



【図９】



フロントページの続き

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(54) METHOD FOR DETECTING FLAW INSIDE OBJECT, APPARATUS FOR LOCATING THE FLAW, AND DISPLAY

(57)Abstract:

PROBLEM TO BE SOLVED: To provide a method in which a flaw inside an object can be located precisely, in which the size of the flaw can be measured precisely, which can be automated and which is objective when the method is used for a complicated shape, a complicated size and an uneven surface to be heated.

SOLUTION: A system which partitions a flaw inside an object is composed of a heater which heats the surface of the object, of a recorder which records the intensity of a pixel on the heated surface, of a means which decides the contrast of the pixel on the basis of the intensity of the pixel and of a means which decides the size and the position of the flaw inside the object on the basis of the contrast of the pixel. Then, the contrast of every pixel is monitored regarding a continuous thermal image, and the position of the flaw inside the object is decided by using the contrast of the pixel. The surface of the object and the flaw which is situated under it are drawn on an image print at a color spectrum which is related to the depth of the flaw having a specific color.

CLAIMS

[Claim(s)]

[Claim 1]A detecting method of a crack within a subject which has the surface divided into arrangement of a resolving element characterized by comprising the following.

A process of heating the surface of a subject.

A process of recording two or more thermal images of each resolving element corresponding to a pixel on said heated surface over predetermined time.

A process of determining intensity of each pixel about each pixel of said pixel in each of said thermal image.

A process of determining average pixel intensity about each thermal image.

A process of acquiring contrast of a pixel about each of said pixel in each of said thermal image by deducting said average pixel intensity from intensity of each pixel of said.

A process of determining the depth of a crack within said subject based on contrast of said pixel.

[Claim 2]Contrast of said pixel is used, a peak of the pixel contrast is acquired, and they are the following formulas. [Equation 1]The method of determining the depth of a crack by, as for l=root (kappatau$_{peak}$/3), however tau$_{peak}$, l's using the depth of a crack for peak time, using it, and kappa's using the thermal diffusivity of a subject, and determining the position of a crack according to claim 1.

[Claim 3]A method according to claim 1 which calculates time differential of contrast of said pixel and is characterized by determining the depth of a crack by acquiring a peak of differentiation contrast.

[Claim 4]The following formulas [Equation 2]The method of, as for l=(pi/2) root (kappatau$_c$), however tau$_c$, l's using the depth of a crack for specific time constants, using it, and kappa's using the thermal diffusivity of a subject, and determining the depth of a crack according to claim 3.

[Claim 5]The following formulas [Equation 3]The method of, as for l=piroot (kappatau$_c$), however tau$_c$, l's using the depth of a crack for specific time constants, using it, and kappa's using the thermal diffusivity of a subject, and determining the depth of a crack according to claim 3.

[Claim 6]A method according to claim 1 including a process of generating an image print of a subject which displays the depth of a crack, and a lateral position using a color spectrum.

[Claim 7]A device which positions a crack within a subject which has the surface which can be visualized as arrangement of a pixel, comprising:

A heater which heats the surface of a subject.

A recorder which records intensity of a pixel.

A means to determine contrast of a pixel from intensity of said pixel.

A means to determine the depth and a position of a crack within said subject based on contrast of said pixel.

[Claim 8]The device according to claim 7, wherein said heater is a flash lamp, a quartz mercury lamp, a microwave device, or laser.

[Claim 9]The following formulas[Equation 4]The device according to claim 7, as for l=root ($kappatau_{peak}$/3), however tau_{peak}, l's using the depth of a crack for peak time, using it, and kappa's using the thermal diffusivity of a subject, and determining the depth of each crack from the contrast of said pixel.

[Claim 10]The following formulas [Equation 5]The device according to claim 7, as for l=(pi/2) root ($kappatau_c$), however tau_c, l's using the depth of a crack for specific time constants, using it, and kappa's using the thermal diffusivity of a subject, and determining the depth of each crack from the differential coefficient of the contrast of said pixel.

[Claim 11]The following formulas [Equation 6]The method of, as for l=piroot ($kappatau_c$), however tau_c, l's using the depth of a crack for specific time constants, using it, and kappa's using the thermal diffusivity of a subject, and determining the depth of each crack from the differential coefficient of the contrast of said pixel according to claim 7.

[Claim 12]The device according to claim 7 containing a means to generate an image print which displays the depth of a crack, and a lateral position using a color spectrum.

[Claim 13]A display of a crack of a subject in which it has the surface shown by two or more resolving elements characterized by comprising the following.

A color spectrum relevant to the depth and mutual.

A means to determine the depth of a crack under each resolving element of the surface of said subject.

A means to display the depth of a crack, and the surface of a subject which has a crack drawn by a color relevant to mutual.

[Claim 14]The display according to claim 13 containing with a means to display a crack on an image print.

DETAILED DESCRIPTION

[Detailed Description of the Invention]

[0001]

[Field of the Invention]This invention relates to the imaging technology which displays the nondestructive tests and these cracks of the subject which determines the depth of the crack (defect) under the surface, and a lateral position especially using unsteady thermography (transient thermography) about a nondestructive test.

[0002]

[Description of the Prior Art]Various art containing the unsteady thermography depending on transfer of the heat which passes along a subject in predetermined time can determine existence of the crack within a subject. By catching the data of a series of picture arrangement using an infrared camera, while heating the surface, the unsteady thermography method records the rise in heat of each resolving element (decomposition element), and analyzes this rise in heat, It consists of identifying whether the transition to a linear rise in heat takes place to the square root of cooking time. The rise in heat of this linearity shows existence of the crack within a subject. With the actual condition, this determination is difficult and becomes still more difficult with a complicated shape dimension and uneven heating.

[0003]The conventional unsteady thermography consists of analyzing each surface infrared image "snapshot" which the subject as a function of time heated beforehand. Since heat cannot distribute by the crack, the crack under the surface is identified by the "hot spot" within the picture which emits the infrared rays of strong intensity. One of the problems of this conventional process is choosing one snapshot in analysis of unsteady thermography, when just right. It is important which snapshot is chosen because of analysis, and the best selection is based on the element of out of control and strange many like the depth of a crack, or a size. If the mistaken snapshot is chosen, the crack shown in a front snapshot or a subsequent snapshot is undetectable.
[0004]In order to avoid use of a snapshot, the video recovery of the picture on which the inspector was recorded is seen, and the bright spot which shows a crack is identified visually. Cannot automate easily but the problem of this method has the high dependence to an operator, It is being unable to determine correctly the position (henceforth the "position") or size of the actual depth of that crack, and a transverse direction, even if it cannot apply to a complicated shape dimension or an uneven heated side easily and can detect a crack by this method.
[0005]In the former, the crack was positioned by ultrasonic testing of the subject. The ultrasonic wave which invades from the surface substantially and is reflected by the crack within a subject is applied by the subject. The position of a crack can be determined based on time required to receive a reflected wave.
[0006]
[Problem(s) to be Solved by the Invention]Ultrasonic testing carries out the mechanical scanning of the transducer over the whole surface by contact of the close sound wave needed. In order to enable contact of a close sound wave, the flow of the catalyst substance of a fluid or all the dipping of a subject must be used, but this is nonpermissible for a substantial reason in many cases. In addition to the problem of a process, this art is not helpful in order to examine a large subject and a complicated subject. Typically, in order to perform a several square meters mechanical scanning, it takes several hours. The scanning system for complicated parts is complicated, and geometrically expensive.
[0007]It can be used for a complicated shape dimension and the uneven heated surface, positioning of the crack within a subject and measurement of a size can be performed correctly, it automates, and it is objective unsteady thermography depth imaging technology that it is required of this art.
[0008]
[Means for Solving the Problem]This invention relates to nondestructive test art of positioning a crack within a subject, and its device. This device consists of a heater which heats the surface of a subject, a recorder which records intensity of each pixel of the heated surface, a means to determine contrast of a pixel from surface intensity, and a means to determine a size and a position of a crack within a subject based on contrast of a pixel.
[0009]A process at which this method heats the surface of a subject, and a process of recording a continuous thermal image of each surface resolving element over predetermined time, A process of determining contrast of each resolving element (pixel) about each surface continuous thermal image by determining average pixel intensity of the thermal image, and deducting average pixel intensity from intensity of each pixel, It consists of a process of determining a position of a crack within a subject based on contrast of a pixel.
[0010]
[Embodiment of the Invention]This invention relates to the automatic non-destructive test

method which determines the size and position of a crack within a subject using unsteady thermography analytical skills. This method is the method of using time-temperature data, in order to detect the crack within a subject objective by supervising change of the skin temperature of the heated thing to time, heats the surface of a subject and consists of supervising the thermal time constant about each pixel of the surface of a subject. In this application specification, a pixel is a picture element of the rectangle under picture arrangement, and a resolving element is a field of the rectangle of the surface of the subject corresponding to one pixel.

[0011]The device used in order to heat the surface of a subject can heat the surface to sufficient temperature, in order to enable thermography surveillance. Typically, a thin subject, for example, the subject of the thickness below about 0.125 inch (0.57 mm), only needs heating of the minimum with a low temperature of about 1 ** as much as possible at the temperature of about 5 ** or less. On the other hand, a thick subject needs heating of a quite high temperature, for example, needs about 20 ** heating in a 0.5-inch thick subject. A color and the element of the surface containing emissivity are also important for the determination of the grade which heats a subject, and the heating maximum of the temperature which damages neither a subject nor its surface by a physical property is specified.

[0012]In order to determine the position and size of a crack correctly, the surface of a subject is heated to a desired temperature in time short enough, and the remaining portion of a subject must be made not to be heated. Typically, although heating takes place with what [for 1 second / 1/] with a thin material, it takes for several minutes with a flash plate with a thicker or large material. If heat invades into a subject, the flaw detecting accuracy near the surface of a subject will fall. For example, although the composite article of a 0.125-inch-thick graphite fiber and polymer can be heated in several milliseconds by the four MW thermal pulse from a flash lamp, By the 2-kW thermal pulse from a quartz mercury lamp, a 0.5-inch-thick subject does not have for several seconds, and must be heated for several minutes. Other possible heating methods include use, such as other conventional heating methods in which microwave, laser, and hot and high-speed heating are possible.

[0013]If the surface of a subject is heated, an infrared video camera will record and memorize the continuous thermal image of the surface of a subject, and will record each of that pixel. It depends for the number of the pictures recorded on the resolution of a request of a thermal image produced as a result, the speed of a camera, and the damping time constant of a specific subject (see the following). Although one thermal image can be formed using about ten pictures, sufficient resolution can be typically provided by about 25 pictures, and the good resolution of a thermal image can be provided by about 100 pictures. Generally with the present video art, about 500 or less pictures can be acquired, and about 25 or more pictures are preferred.

[0014]When arranging heating apparatus and a video camera to the same subject side, damping time constant tau_c used in order to specify the time for obtaining a thermal image is obtained from the formula 4. Here, the depth is the thickness of a subject.

[0015]

[Equation 7]$tau_c=4l.^2/(pi^2 kappa)$ -- (1)

However, when the thermal-diffusivity l= depth camera and heater of a tau_c= "peculiar" damping time constant kappa= subject have been arranged to the opposite hand of a subject, the coefficient 4 is omitted from (1) type. The time used in order that the inside of a subject may obtain a thermal image to a thermal balance after about 5 specific time constants by that of ** which is ** is typically equal to damping time constant tau_c of about 3 thru/or about 5, or the damping time constant beyond it.

[0016]The high-speed focal plane array camera or same device with a camera temperature sensitivity of at least about 0.01 ** thru/or about 0.02 ** of a video device is preferred from at least about 60 frames per second at the frame rate beyond about 250 or less frames per second or it. The minimum allowable resolution has the typically preferred resolution of 128x128 or more pixels depending on the solution resolution of a request of a final image print.
[0017]The thermal image memorized in order to determine the contrast of each pixel by deducting the intensity (a) of each pixel [in / for the average pixel intensity (b) of the picture (a butterfly and a point when good) / a point when just right] is used. Next, this contrast is plotted to time about each pixel (refer to drawing 2). As for the contrast of the portion of a crack, when the picture is acquired with a video camera, the number of pictures reaches a peak. If it may become a peak, the depth of a crack can be determined and the approximate value of the depth will be acquired by (2) types.
[0018]
[Equation 8]l=root (kappatau$_{peak}$/3) -- (2)
However, the "thermal-diffusivity (2)" type of the medium measured by l= depth tau$_c$= "peculiar" damping time constant kappa=cgs unit cm^2/sec, It is useful especially when it is a crack of "penetration heat" in which heat does not flow around a crack with the thickness of a crack (see the crack of the "penetration heat" of drawing 3 A to the crack of the "side heat" of drawing 3 B).
[0019]However, when the diffusion rate of the surrounding heat of a crack is quicker than the diffusion rate of the heat which penetrates a crack (drawing 3 B), the peak of contrast does not appear in the graph of the contrast of a pixel clearly (drawing 4). Therefore, in order to determine the peak of differentiation contrast, a contrast curve is differentiated from time. The depth of the crack of "side heat" can be determined from the time of a peak using the following formulas 6.
[0020]
[Equation 9]The "thermal diffusivity" of the medium measured by inflection time kappa=cgs unit cm^2/sec of the l=0.524piroot(kappatau$_i$) tau$_c$=1.10tau$_i$, however l= depth tau$_c$= "peculiar" damping time constant tau$_i$= differentiation peak
The accuracy of example this invention was specified using the subject which has a series of flat cracks arranged carefully. As shown in drawing 6, and 6A, 6B and 6C, the cracks 1, 2, 3, 4, and 5 have 22 same mm in diameter, and 1.3 mm, 1.6 mm, 1.9 mm, 2.2 mm, and 2.5 mm differ from the depth, respectively. The cracks 6, 7, 8, 9, 10, and 11 have same depth of 1.3 mm, and have a different diameter of 22 mm, 16.5 mm, 11 mm, 8.25 mm, 5.5 mm, and 2.75 mm, respectively. The cracks 12, 13, and 14 have 33 same mm in diameter, and 1.3 mm, 1.9 mm, and 2.5 mm differ from the depth, respectively.
[0021]The test parameter is as follows. (1) Each image frame consists of a NxN (it corresponds to resolving element of the surface of subject) pixel in case N is 256, (2) Typically, several Z of the image frame of the range of 1 thru/or 200 is [128 / N=] 100 about 1 thru/or 400, and N= 256, and (3) each pixel occupies 2 bytes of memory storage, and is shown by 12 numbers of bits from 0 to 4095 which shows thermal radiation intensity.
[0022]A subject was heated for 0.010 second at about 5 ** by the four MW thermal pulse from a flash lamp. A high-speed focal plane array camera which operates it for about 25 seconds and has the resolution of a pixel of 256x256 after heating was used, intensity of each resolving element was recorded, and 12 bits showed each pixel. A user's parameter was determined and it put into a system. The system is provided with the following.
A start-up frame number for using it for analysis (a frame taken before the surface was heated was omitted).

Squelch constant.
Noise suppression (a position of a pixel whose absolute value of what lengthened a starting value or the last value from a peak of a contrast curve is smaller than this constant is thrown away).
Field of view (it is the distance from an infrared camera to a subject, and scaling is permitted, therefore determination of an exact size is permitted).
A twice [fixed contrast gain] as many difference as average value of a pixel and a pixel was used for contrast of each pixel, and it determined it about average pixel intensity of the whole picture. This operation followed each pixel of each image frame which generates a contrast curve of a lot. Next, 6 point-lead method was used and a differential coefficient of each contrast curve was determined. Information on a peak of differentiation contrast was memorized by controlling this information about a position of a pixel which shows storage, low contrast, or a noise for the number of image frames which generates a peak of each differentiation contrast curve. Next, the depth of a crack was determined using a position of an image frame which a peak of differentiation contrast produces. The depth of these cracks was visually shown using an intensity color spectrum as shown in drawing 7. A number of a crack shown in drawing 7, drawing 8, and drawing 9 is in agreement with a number of drawing 6 in which a crack detected by drawing 7, drawing 8, and drawing 9 is shown.
[0023]An image print of a crack was generated by assigning the number of peak frames memorized about each pixel to one of the colors in 16 color palettes shown in right-hand side of drawing 7, drawing 8, and drawing 9. This divided a total (16) of a color by a frame total (100), and performed it by applying the number of peak frames about a predetermined pixel. Next, this number was rounded off to an integral index, and it put into a color palette which chooses one of the 16 colors which can display this pixel. This process was repeated about all the picture element positions of a picture. This picture was made still better using four intensity levels of each color shown in the right from the left of a color palette of drawing 7, drawing 8, and drawing 9. A maximum peak corresponds to the highest intensity (level 1) of a predetermined color, and the minimum peak corresponds to the minimum intensity (level 4) of a predetermined color (see drawing 7, drawing 8, and drawing 9).
[0024]By contrast, drawing 8 shows an image print by this invention which shows the conventional imaging technology depending on a snapshot of a strong profile. Since all the cracks were clear so that clearly from this drawing 8, when just right, a "snapshot" was taken on a good point. However, most cracks seem to arrange in the same depth. Therefore, the depth exact about which crack cannot be determined. It is difficult for the crack 11 to only look small and to specify as one crack.
[0025]Drawing 9 is an image print which uses the conventional unsteady thermography, and provides information which gets confused similarly. In this figure, it seems that an edge of a crack is shallower than the central part of a crack. Therefore, although a crack is flat, it looks like a concave surface. The depth of a crack cannot be determined correctly.
[0026]This invention provides many advantages compared with the conventional nondestructive test. That is, a personal error is removed substantially, positioning capability of a crack is provided, and a picture is simplified. The conventional process had only detected existence of a crack depending on surface single "snapshot", i.e., a personal error, depending on an operator which looks at many pictures.Although the depth and a size of a crack can be correctly determined in this invention, the depth is correctly undetectable in a conventional method.
[0027]According to this invention, as explained above, it can be used for a complicated shape dimension and the uneven heated surface, and positioning of a crack within a subject and

measurement of a size can be performed correctly, it can automate and an objective method is provided.

[0028]A system concerning this invention which positions a crack within a subject, A heater which heats the surface of a subject, and a recorder which records intensity of each pixel on the heated surface, It consists of a means to determine contrast of a pixel from intensity of a pixel, and a means to determine a size and a position of a crack within a subject based on contrast of a pixel, Contrast of each pixel is supervised about a continuous thermal image, and a position of a crack within a subject is determined using contrast of these pixels. A crack in the surface of a subject and the bottom of it is drawn on an image print of a color spectrum relevant to [which have a specific color / the depth of a crack and mutual].

TECHNICAL FIELD

[Field of the Invention]This invention relates to the imaging technology which displays the nondestructive tests and these cracks of the subject which determines the depth of the crack (defect) under the surface, and a lateral position especially using unsteady thermography (transient thermography) about a nondestructive test.

PRIOR ART

[Description of the Prior Art]Various art containing the unsteady thermography depending on transfer of the heat which passes along a subject in predetermined time can determine existence of the crack within a subject. By catching the data of a series of picture arrangement using an infrared camera, while heating the surface, the unsteady thermography method records the rise in heat of each resolving element (decomposition element), and analyzes this rise in heat, It consists of identifying whether the transition to a linear rise in heat takes place to the square root of cooking time. The rise in heat of this linearity shows existence of the crack within a subject. With the actual condition, this determination is difficult and becomes still more difficult with a complicated shape dimension and uneven heating.

[0003]The conventional unsteady thermography consists of analyzing each surface infrared image "snapshot" which the subject as a function of time heated beforehand. Since heat cannot distribute by the crack, the crack under the surface is identified by the "hot spot" within the picture which emits the infrared rays of strong intensity. One of the problems of this conventional process is choosing one snapshot in analysis of unsteady thermography, when just right. It is important which snapshot is chosen because of analysis, and the best selection is based on the element of out of control and strange many like the depth of a crack, or a size. If the mistaken snapshot is chosen, the crack shown in a front snapshot or a subsequent snapshot is undetectable.

[0004]In order to avoid use of a snapshot, the video recovery of the picture on which the inspector was recorded is seen, and the bright spot which shows a crack is identified visually.

Cannot automate easily but the problem of this method has the high dependence to an operator, It is being unable to determine correctly the position (henceforth the "position") or size of the actual depth of that crack, and a transverse direction, even if it cannot apply to a complicated shape dimension or an uneven heated side easily and can detect a crack by this method.
[0005]In the former, the crack was positioned by ultrasonic testing of the subject. The ultrasonic wave which invades from the surface substantially and is reflected by the crack within a subject is applied by the subject. The position of a crack can be determined based on time required to receive a reflected wave.

TECHNICAL PROBLEM

[Problem(s) to be Solved by the Invention]Ultrasonic testing carries out the mechanical scanning of the transducer over the whole surface by contact of the close sound wave needed. In order to enable contact of a close sound wave, the flow of the catalyst substance of a fluid or all the dipping of a subject must be used, but this is nonpermissible for a substantial reason in many cases. In addition to the problem of a process, this art is not helpful in order to examine a large subject and a complicated subject. Typically, in order to perform a several square meters mechanical scanning, it takes several hours. The scanning system for complicated parts is complicated, and geometrically expensive.
[0007]It can be used for a complicated shape dimension and the uneven heated surface, positioning of the crack within a subject and measurement of a size can be performed correctly, it automates, and it is objective unsteady thermography depth imaging technology that it is required of this art.

MEANS

[Means for Solving the Problem]This invention relates to nondestructive test art of positioning a crack within a subject, and its device. This device consists of a heater which heats the surface of a subject, a recorder which records intensity of each pixel of the heated surface, a means to determine contrast of a pixel from surface intensity, and a means to determine a size and a position of a crack within a subject based on contrast of a pixel.
[0009]A process at which this method heats the surface of a subject, and a process of recording a continuous thermal image of each surface resolving element over predetermined time, A process of determining contrast of each resolving element (pixel) about each surface continuous thermal image by determining average pixel intensity of the thermal image, and deducting average pixel intensity from intensity of each pixel, It consists of a process of determining a position of a crack within a subject based on contrast of a pixel.
[0010]
[Embodiment of the Invention]This invention relates to the automatic non-destructive test

method which determines the size and position of a crack within a subject using unsteady thermography analytical skills. This method is the method of using time-temperature data, in order to detect the crack within a subject objective by supervising change of the skin temperature of the heated thing to time, heats the surface of a subject and consists of supervising the thermal time constant about each pixel of the surface of a subject. In this application specification, a pixel is a picture element of the rectangle under picture arrangement, and a resolving element is a field of the rectangle of the surface of the subject corresponding to one pixel.

[0011]The device used in order to heat the surface of a subject can heat the surface to sufficient temperature, in order to enable thermography surveillance. Typically, a thin subject, for example, the subject of the thickness below about 0.125 inch (0.57 mm), only needs heating of the minimum with a low temperature of about 1 ** as much as possible at the temperature of about 5 ** or less. On the other hand, a thick subject needs heating of a quite high temperature, for example, needs about 20 ** heating in a 0.5-inch thick subject. A color and the element of the surface containing emissivity are also important for the determination of the grade which heats a subject, and the heating maximum of the temperature which damages neither a subject nor its surface by a physical property is specified.

[0012]In order to determine the position and size of a crack correctly, the surface of a subject is heated to a desired temperature in time short enough, and the remaining portion of a subject must be made not to be heated. Typically, although heating takes place with what [for 1 second / 1/] with a thin material, it takes for several minutes with a flash plate with a thicker or large material. If heat invades into a subject, the flaw detecting accuracy near the surface of a subject will fall. For example, although the composite article of a 0.125-inch-thick graphite fiber and polymer can be heated in several milliseconds by the four MW thermal pulse from a flash lamp, By the 2-kW thermal pulse from a quartz mercury lamp, a 0.5-inch-thick subject does not have for several seconds, and must be heated for several minutes. Other possible heating methods include use, such as other conventional heating methods in which microwave, laser, and hot and high-speed heating are possible.

[0013]If the surface of a subject is heated, an infrared video camera will record and memorize the continuous thermal image of the surface of a subject, and will record each of that pixel. It depends for the number of the pictures recorded on the resolution of a request of a thermal image produced as a result, the speed of a camera, and the damping time constant of a specific subject (see the following). Although one thermal image can be formed using about ten pictures, sufficient resolution can be typically provided by about 25 pictures, and the good resolution of a thermal image can be provided by about 100 pictures. Generally with the present video art, about 500 or less pictures can be acquired, and about 25 or more pictures are preferred.

[0014]When arranging heating apparatus and a video camera to the same subject side, damping time constant tau_c used in order to specify the time for obtaining a thermal image is obtained from the formula 4. Here, the depth is the thickness of a subject.

[0015]

[Equation 7]$tau_c=4l.^2/(pi^2 kappa)$ -- (1)

However, when the thermal-diffusivity l= depth camera and heater of a tau_c= "peculiar" damping time constant kappa= subject have been arranged to the opposite hand of a subject, the coefficient 4 is omitted from (1) type. The time used in order that the inside of a subject may obtain a thermal image to a thermal balance after about 5 specific time constants by that of ** which is ** is typically equal to damping time constant tau_c of about 3 thru/or about 5, or the damping time constant beyond it.

[0016]The high-speed focal plane array camera or same device with a camera temperature sensitivity of at least about 0.01 ** thru/or about 0.02 ** of a video device is preferred from at least about 60 frames per second at the frame rate beyond about 250 or less frames per second or it. The minimum allowable resolution has the typically preferred resolution of 128x128 or more pixels depending on the solution resolution of a request of a final image print.

[0017]The thermal image memorized in order to determine the contrast of each pixel by deducting the intensity (a) of each pixel [in / for the average pixel intensity (b) of the picture (a butterfly and a point when good) / a point when just right] is used. Next, this contrast is plotted to time about each pixel (refer to drawing 2). As for the contrast of the portion of a crack, when the picture is acquired with a video camera, the number of pictures reaches a peak. If it may become a peak, the depth of a crack can be determined and the approximate value of the depth will be acquired by (2) types.

[0018]

[Equation 8]l=root ($kappatau_{peak}$/3) -- (2)

However, the "thermal-diffusivity (2)" type of the medium measured by l= depth tau_c= "peculiar" damping time constant kappa=cgs unit cm^2/sec, It is useful especially when it is a crack of "penetration heat" in which heat does not flow around a crack with the thickness of a crack (see the crack of the "penetration heat" of drawing 3 A to the crack of the "side heat" of drawing 3 B).

[0019]However, when the diffusion rate of the surrounding heat of a crack is quicker than the diffusion rate of the heat which penetrates a crack (drawing 3 B), the peak of contrast does not appear in the graph of the contrast of a pixel clearly (drawing 4). Therefore, in order to determine the peak of differentiation contrast, a contrast curve is differentiated from time. The depth of the crack of "side heat" can be determined from the time of a peak using the following formulas 6.

[0020]

[Equation 9]The "thermal diffusivity" of the medium measured by inflection time kappa=cgs unit cm^2/sec of the l=0.524piroot($kappatau_i$) tau_c=1.10tau_i, however l= depth tau_c= "peculiar" damping time constant tau_i= differentiation peak

The accuracy of example this invention was specified using the subject which has a series of flat cracks arranged carefully. As shown in drawing 6, and 6A, 6B and 6C, the cracks 1, 2, 3, 4, and 5 have 22 same mm in diameter, and 1.3 mm, 1.6 mm, 1.9 mm, 2.2 mm, and 2.5 mm differ from the depth, respectively. The cracks 6, 7, 8, 9, 10, and 11 have same depth of 1.3 mm, and have a different diameter of 22 mm, 16.5 mm, 11 mm, 8.25 mm, 5.5 mm, and 2.75 mm, respectively. The cracks 12, 13, and 14 have 33 same mm in diameter, and 1.3 mm, 1.9 mm, and 2.5 mm differ from the depth, respectively.

[0021]The test parameter is as follows. (1) Each image frame consists of a NxN (it corresponds to resolving element of the surface of subject) pixel in case N is 256, (2) Typically, several Z of the image frame of the range of 1 thru/or 200 is [128 / N=] 100 about 1 thru/or 400, and N= 256, and (3) each pixel occupies 2 bytes of memory storage, and is shown by 12 numbers of bits from 0 to 4095 which shows thermal radiation intensity.

[0022]A subject was heated for 0.010 second at about 5 ** by the four MW thermal pulse from a flash lamp. A high-speed focal plane array camera which operates it for about 25 seconds and has the resolution of a pixel of 256x256 after heating was used, intensity of each resolving element was recorded, and 12 bits showed each pixel. A user's parameter was determined and it put into a system. The system is provided with the following.

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Squelch constant.

Noise suppression (a position of a pixel whose absolute value of what lengthened a starting value or the last value from a peak of a contrast curve is smaller than this constant is thrown away).

Field of view (it is the distance from an infrared camera to a subject, and scaling is permitted, therefore determination of an exact size is permitted).

A twice [fixed contrast gain] as many difference as average value of a pixel and a pixel was used for contrast of each pixel, and it determined it about average pixel intensity of the whole picture. This operation followed each pixel of each image frame which generates a contrast curve of a lot. Next, 6 point-lead method was used and a differential coefficient of each contrast curve was determined. Information on a peak of differentiation contrast was memorized by controlling this information about a position of a pixel which shows storage, low contrast, or a noise for the number of image frames which generates a peak of each differentiation contrast curve. Next, the depth of a crack was determined using a position of an image frame which a peak of differentiation contrast produces. The depth of these cracks was visually shown using an intensity color spectrum as shown in drawing 7. A number of a crack shown in drawing 7, drawing 8, and drawing 9 is in agreement with a number of drawing 6 in which a crack detected by drawing 7, drawing 8, and drawing 9 is shown.

[0023]An image print of a crack was generated by assigning the number of peak frames memorized about each pixel to one of the colors in 16 color palettes shown in right-hand side of drawing 7, drawing 8, and drawing 9. This divided a total (16) of a color by a frame total (100), and performed it by applying the number of peak frames about a predetermined pixel. Next, this number was rounded off to an integral index, and it put into a color palette which chooses one of the 16 colors which can display this pixel. This process was repeated about all the picture element positions of a picture. This picture was made still better using four intensity levels of each color shown in the right from the left of a color palette of drawing 7, drawing 8, and drawing 9. A maximum peak corresponds to the highest intensity (level 1) of a predetermined color, and the minimum peak corresponds to the minimum intensity (level 4) of a predetermined color (see drawing 7, drawing 8, and drawing 9).

[0024]By contrast, drawing 8 shows an image print by this invention which shows the conventional imaging technology depending on a snapshot of a strong profile. Since all the cracks were clear so that clearly from this drawing 8, when just right, a "snapshot" was taken on a good point. However, most cracks seem to arrange in the same depth. Therefore, the depth exact about which crack cannot be determined. It is difficult for the crack 11 to only look small and to specify as one crack.
[0025]Drawing 9 is an image print which uses the conventional unsteady thermography, and provides information which gets confused similarly. In this figure, it seems that an edge of a crack is shallower than the central part of a crack. Therefore, although a crack is flat, it looks like a concave surface. The depth of a crack cannot be determined correctly.
[0026]This invention provides many advantages compared with the conventional nondestructive test. That is, a personal error is removed substantially, positioning capability of a crack is provided, and a picture is simplified. The conventional process had only detected existence of a crack depending on surface single "snapshot", i.e., a personal error, depending on an operator which looks at many pictures.Although the depth and a size of a crack can be correctly determined in this invention, the depth is correctly undetectable in a conventional method.
[0027]According to this invention, as explained above, it can be used for a complicated shape dimension and the uneven heated surface, and positioning of a crack within a subject and measurement of a size can be performed correctly, it can automate and an objective method is provided.
[0028]A system concerning this invention which positions a crack within a subject, A heater which heats the surface of a subject, and a recorder which records intensity of each pixel on the heated surface, It consists of a means to determine contrast of a pixel from intensity of a pixel, and a means to determine a size and a position of a crack within a subject based on contrast of a pixel, Contrast of each pixel is supervised about a continuous thermal image, and a position of a crack within a subject is determined using contrast of these pixels. A crack in the surface of a subject and the bottom of it is drawn on an image print of a color spectrum relevant to [which have a specific color / the depth of a crack and mutual].

DESCRIPTION OF DRAWINGS

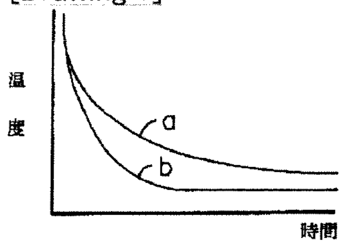
[Brief Description of the Drawings]
[Drawing 1]It is a graph which shows the intensity (temperature) to the time about each pixel (a) to average pixel intensity (b).
[Drawing 2]It is a graph which shows the contrast of the pixel to the time about the pixel of drawing 1, and the peak of contrast is shown.
[Drawing 3]Drawing 3 (A) is a sectional view of the subject in which the film exfoliation which is an example of "the crack of penetration heat" which permits a penetration heat flow is shown. Drawing 3 (B) is a sectional view of the subject in which the thick layer exfoliation which is an example of "the crack of side heat" which mainly needs a lateral heat flow is shown.

[Drawing 4]It is a graph which shows the contrast of the pixel to the time about each pixel which does not have a peak of contrast for "the crack of side heat."

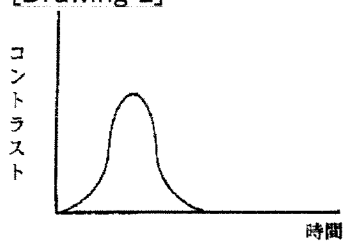
[Drawing 5]In order to show the peak of the differentiation contrast of "the crack of side heat" from drawing 4, it is a graph which shows the differentiation pixel contrast over time about each pixel.
[Drawing 6]Drawing 6 (O), drawing 6 (A), drawing 6 (B), and drawing 6 (C) are the figures showing the relative size of the specimen shown in drawing 7, drawing 8, and drawing 9, and its crack.
[Drawing 7]It is an explanatory view of the image print in which the intensity of a pixel is shown using the thermography art of this invention.
[Drawing 8]It is an explanatory view of the image print of this invention in which the intensity of a pixel is shown using the conventional imaging technology.
[Drawing 9]It is an explanatory view of the image print of this invention in which the intensity of the pixel which shows temperature using the conventional unsteady thermography is shown.
[Description of Notations]
1-14 -- Crack

DRAWINGS

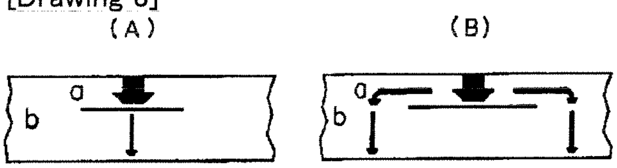
[Drawing 1]



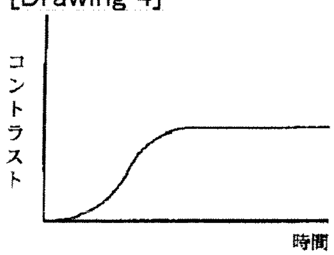
[Drawing 2]



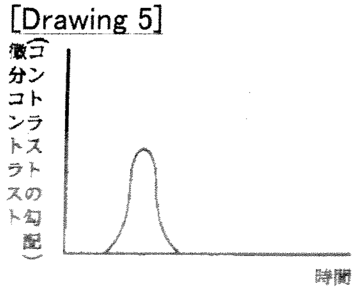
[Drawing 3]



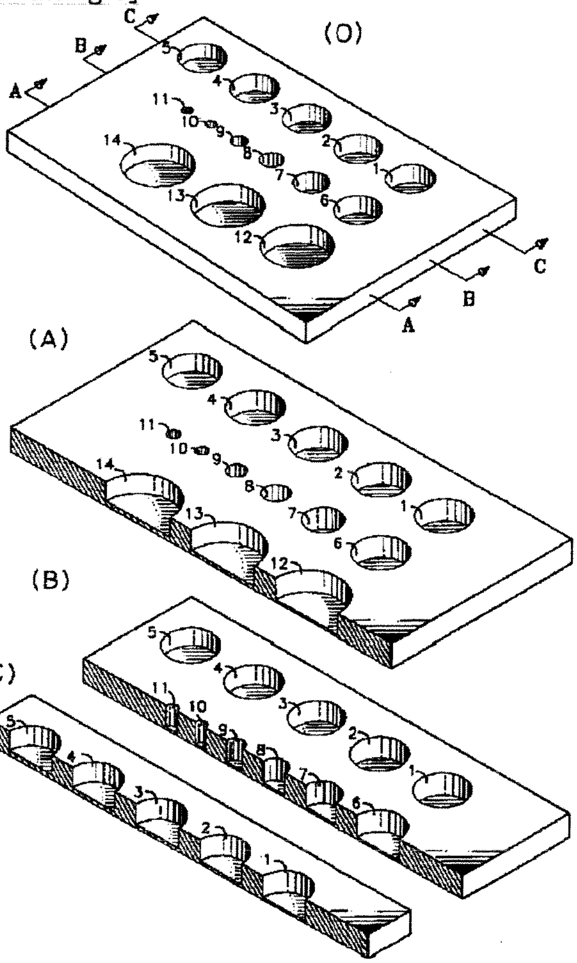
[Drawing 4]



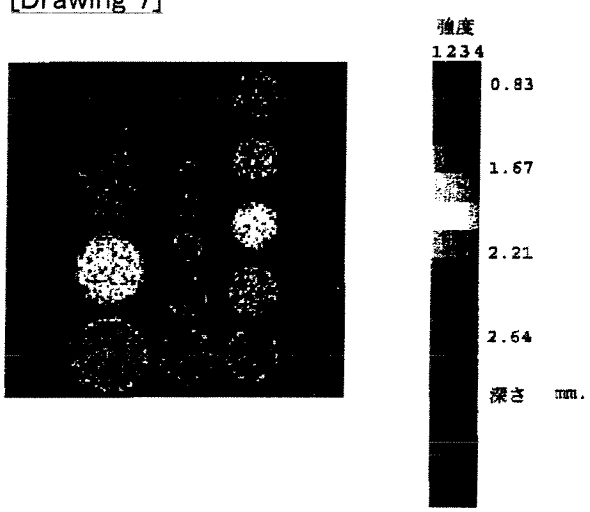
[Drawing 5]



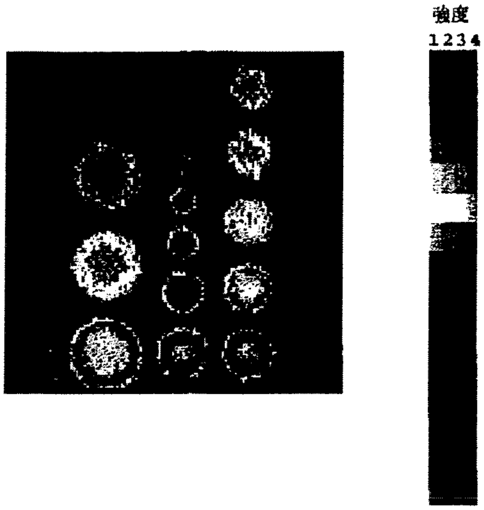
[Drawing 6]



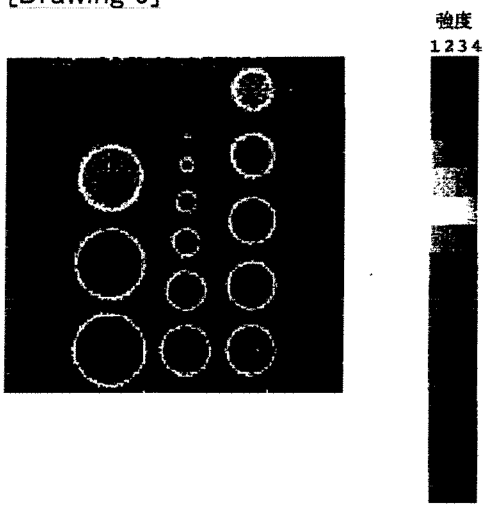
[Drawing 7]



[Drawing 8]



[Drawing 9]



[Translation done.]

US005711603A

United States Patent [19]

Ringermacher et al.

[11] Patent Number: 5,711,603

[45] Date of Patent: Jan. 27, 1998

[54] NONDESTRUCTIVE TESTING: TRANSIENT DEPTH THERMOGRAPHY

[75] Inventors: **Harry I. Ringermacher**, Bloomfield; **Raymond J. Archacki, Jr.**, Wethersfield; **William A. Veronesi**, Hartford, all of Conn.

[73] Assignee: **United Technologies Corporation**, Hartford, Conn.

[21] Appl. No.: **739,572**

[22] Filed: **Oct. 30, 1996**

[51] **Int. Cl.**^{6} **G01N 25/72**

[52] **U.S. Cl.** **374/5**; 374/124; 364/507

[58] **Field of Search** 374/4, 5, 120, 374/121, 124, 137; 250/330, 332, 341.1, 342; 364/507, 557

[56] **References Cited**

U.S. PATENT DOCUMENTS

4,768,158	8/1988	Osanai	374/5
4,854,724	8/1989	Adams et al.	374/5
5,032,727	7/1991	Cox, Jr. et al.	374/5
5,246,291	9/1993	Lebeau et al.	374/5
5,250,809	10/1993	Nakata et al.	374/5
5,292,195	3/1994	Crisman, Jr.	374/124
5,539,656	7/1996	Annigeri et al.	364/507
5,582,485	12/1996	Lesniak	374/5

FOREIGN PATENT DOCUMENTS

2168494	6/1986	United Kingdom	374/5

OTHER PUBLICATIONS

Vladimir P. Vavilov et al. "Thermal Characterization and Tomography of Carbon Fiber Reinforced Plastics Using Individual Identification Technique", *Materials Evaluation*, May 1996 vol. 54, No. 5, pp. 604–610.

Primary Examiner—G. Bradley Bennett
Attorney, Agent, or Firm—Pamela J. Curbelo

[57] ABSTRACT

The present invention relates to transient depth thermography; a nondestructive testing technique and system for locating flaws within an object. The system, which comprises a heater for heating the surface of the object; a recorder for recording pixel intensity for each pixel on the heated surface; a means for determining pixel contrast from the pixel intensity; and a means for determining the size and location of flaws within the object based upon the pixel contrast; monitors each pixels' contrast for successive thermal images and utilizes those pixel contrasts determining the location of a flaw within the object. The object surface and the respective underlying flaws can then be depicted on a color spectrum image print which correlates the flaw depth with a particular color.

14 Claims, 4 Drawing Sheets

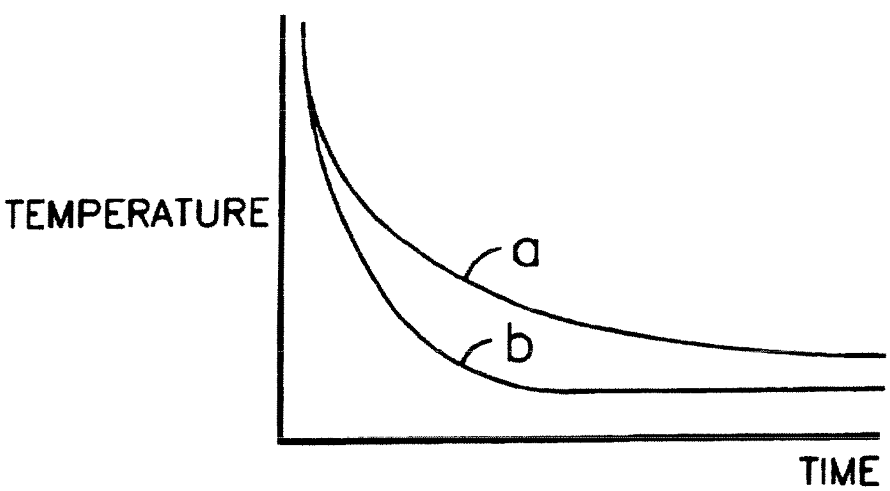


FIG.1

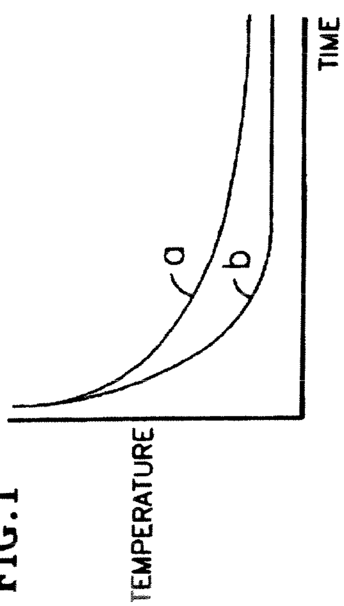


FIG.2

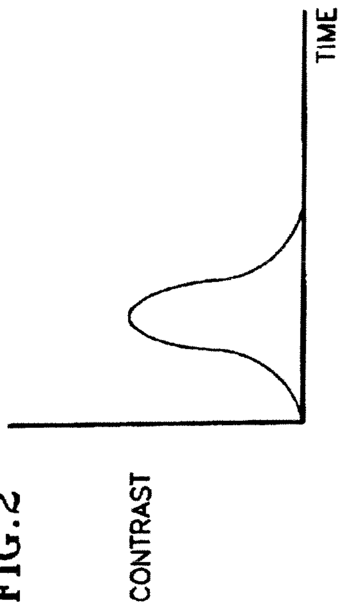


FIG.3A

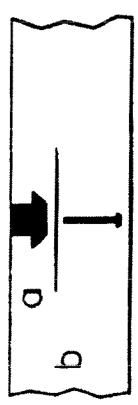


FIG.3B

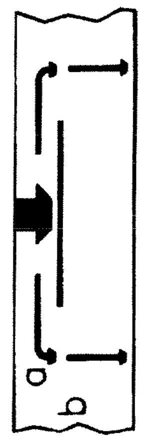


FIG.4

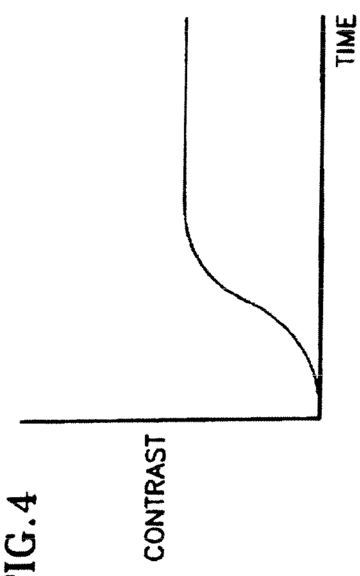
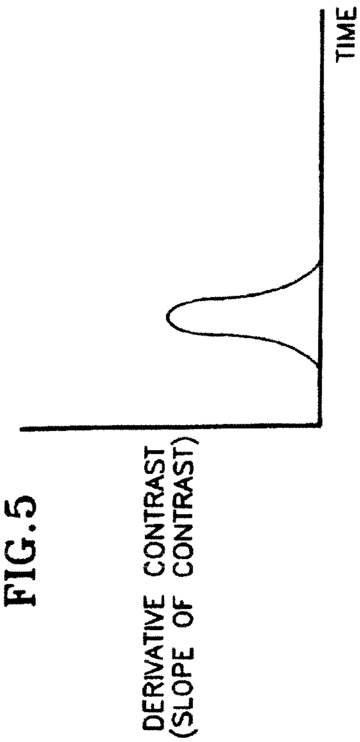


FIG.5



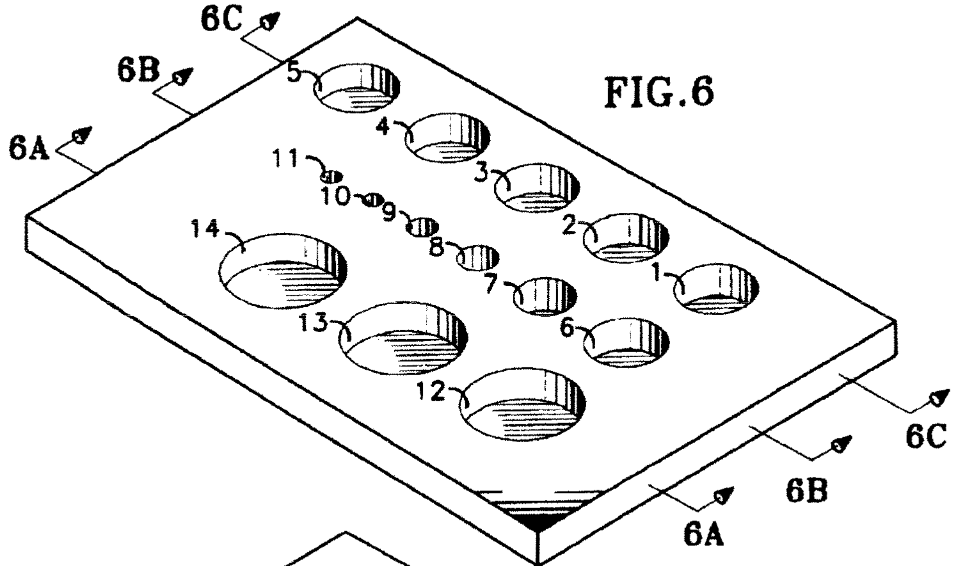


FIG.6

FIG.6A

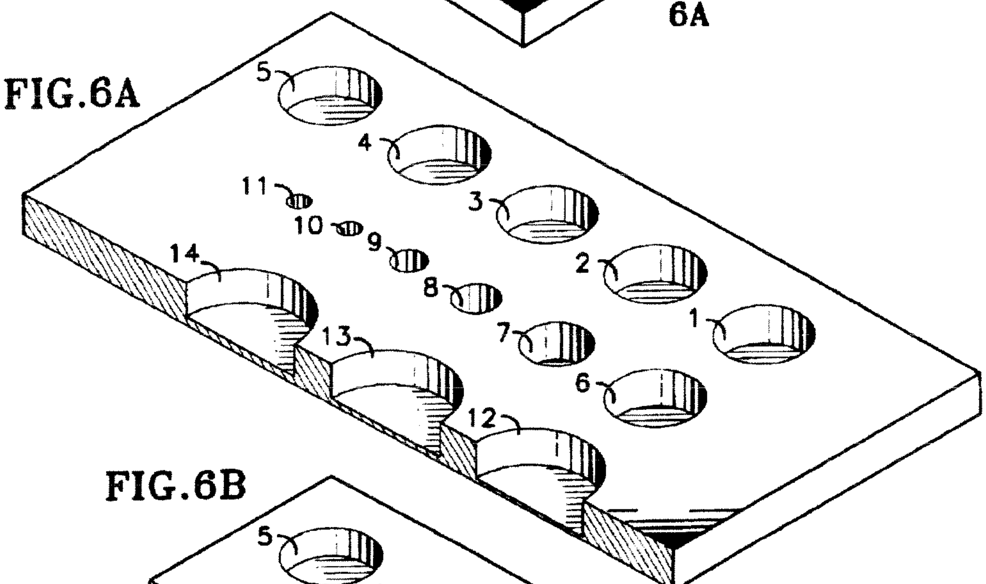
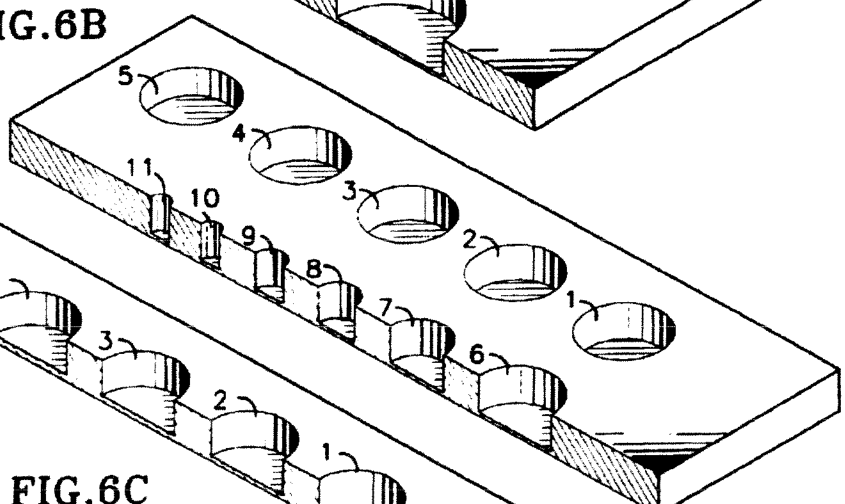


FIG.6B



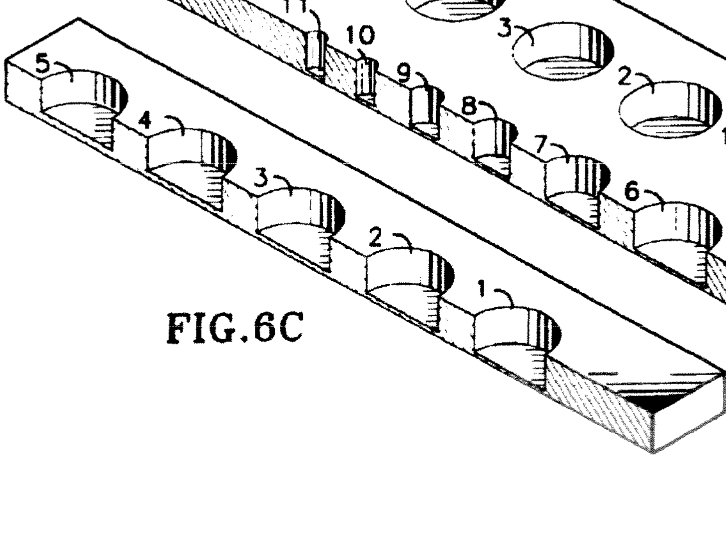


FIG.6C

FIG.7

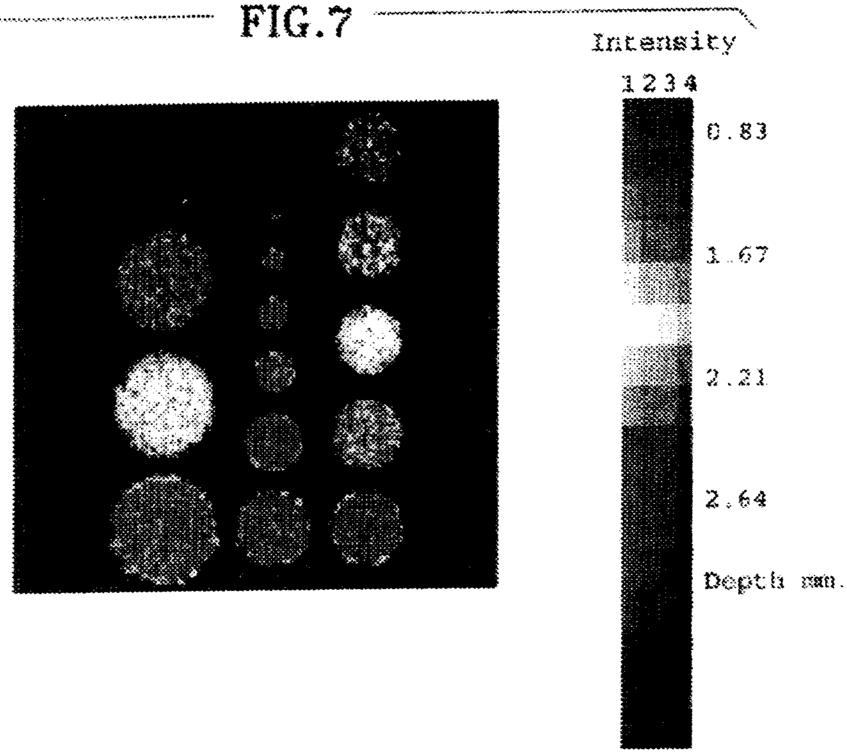


FIG.8

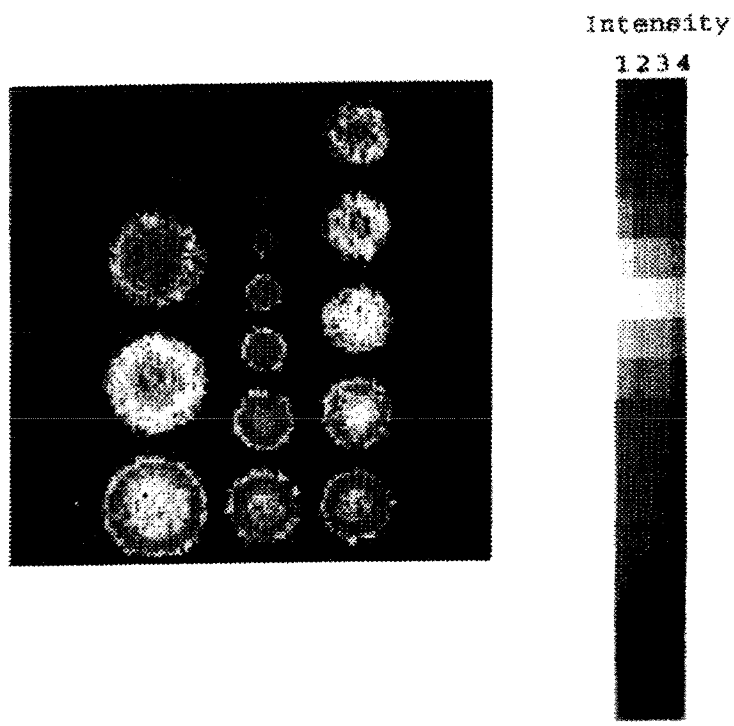
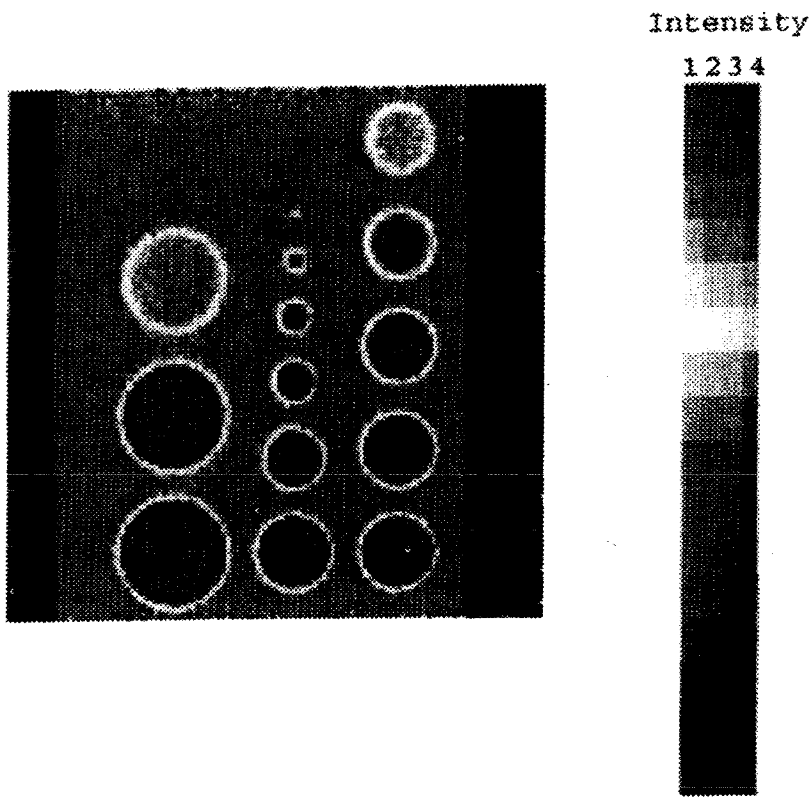


FIG.9



NONDESTRUCTIVE TESTING: TRANSIENT DEPTH THERMOGRAPHY

TECHNICAL FIELD

The present invention relates to nondestructive testing, and especially relates to nondestructive testing of an object to determine the depth and lateral position of subsurface flaws using transient thermography and to an imaging technique for displaying those flaws.

BACKGROUND OF THE INVENTION

The existence of a flaw within an object can be determined by various techniques, including transient thermography which relies upon the transfer of heat through an object over a period of time. One transient thermographic method comprises recording the temperature rise of each resolution element by capturing a series of image arrays using an infrared camera while heating the surface, and analyzing this temperature rise to identify if a transition to a linear temperature increase versus the square root of the heating time, occurs. This linear temperature increase indicates the existence of a flaw within the object. This determination is difficult as is and becomes more difficult with complex geometries and uneven heating.

Conventional transient thermography comprises analyzing individual infrared images, "snap-shots", of an object's previously heated surface as a function of time. Subsurface flaws are identified by "hot spots" in the image which emit greater intensity infrared radiation due to the heat's inability to disperse through the flaw. One problem with this conventional process is that the transient thermographic analysis is reduced to choosing a single snap-shot in time. The choice of which snap-shot to analyze is critical, and the best choice is based on many factors which cannot be controlled and are unknowns, such as depth and size of the flaw. If the incorrect snap-shot is chosen, flaws revealed on a previous or subsequent snap-shots, may not be detected.

To avoid the use of a snap-shot, an inspector watches a video replay of the recorded images and visually identifies bright spots indicative of flaws. The problem with this approach is that it is not readily automated, is highly operator dependent, is not readily applied to complex geometries or unevenly heated surfaces, and although a flaw may be detected with this approach, the actual depth and lateral position (hereinafter location) or size of the flaw cannot be accurately determined.

Conventionally, flaws are located through ultrasonic testing of the object. Essentially the object is struck with ultrasonic waves which penetrate the surface and are reflected by a flaw(s) within the object. Based upon the time required to receive a reflected wave, the location of the flaw can be determined.

Ultrasonic testing employs mechanical scanning with a transducer over the entire surface, with intimate sonic contact required. In order to allow intimate sonic contact, a stream of liquid couplant or total immersion of the object must be used; however, this is often unacceptable for material reasons. In addition to process problems, this technique is inefficient for testing large and/or complex objects. Mechanical scanning of a few square meters typically takes hours. Furthermore, scanning systems for geometrically complex parts are complex and expensive.

What is needed in the art is an automated, objective, transient thermographic depth imaging technique which can be employed with complex geometries and unevenly heated surfaces to accurately locate and size flaws within an object.

SUMMARY OF THE INVENTION

The present invention relates to a nondestructive testing technique and apparatus for locating flaws within an object. The apparatus comprises: a heater for heating the surface of the object; a recorder for recording intensity for each pixel of said heated surface; a means for determining pixel contrast from the surface intensity; and a means for determining the size and location of flaws within the object based upon the pixel contrast.

The method comprises the steps of: heating the surface of the object; recording successive thermal images of each resolution element of the surface over a period of time; determining each resolution element's (pixel's) contrast for each successive thermal image of the surface by determining the mean pixel intensity for that thermal image and subtracting said mean pixel intensity from the individual pixel's intensity; and determining the location of the flaw within the object based upon the pixel contrast.

BRIEF DESCRIPTION OF THE DRAWINGS

The file of this patent contains three drawings executed in color. Copies of this patent with color drawings will be provided by the Patent and Trademark Office upon request and payment of the necessary fee.

FIG. 1 is a graph of the intensity (temperature) versus time for an individual pixel (a) versus the mean pixel intensity (b).

FIG. 2 is a graph of the pixel contrast versus time for the pixels of FIG. 1 to show the contrast peak.

FIG. 3A is a cross-sectional view of an object revealing a thin delamination which is an example of a "through heat flaw" which allows through heat flow.

FIG. 3B is a cross-sectional view of an object revealing a thick delamination which is an example of a "lateral heat flaw" which requires mostly lateral heat flow.

FIG. 4 is a graph of the pixel contrast versus time for an individual pixel where there is no contrast peak due to the type of flaw; a "lateral heat flaw".

FIG. 5 is a graph of the derivative pixel contrast versus time for an individual pixel to show the derivative contrast peak for the "lateral heat flaw" from FIG. 4.

FIGS. 6, 6A, 6B, and 6C illustrate the test specimen and its relative dimensions for the flaws revealed in FIGS. 7, 8, and 9.

FIG. 7 is an image print of pixel intensity using the thermographic technique of the present invention.

FIG. 8 is a present invention image print of pixel intensity using a prior art imaging technique.

FIG. 9 is a present invention image print of pixel intensity representing temperature using prior art transient thermography.

BEST MODE FOR CARRYING OUT THE INVENTION

The present invention is an automated nondestructive testing method which employs a transient thermographic analysis technique to determine the size and location of flaws in an object. This method which preferably uses time-temperature data to objectively detect flaws in an object by monitoring surface temperature variation of a heated object over time comprises: heating the object's

surface and monitoring the thermal time constants for each pixel of the surface of the object. In the context of the present invention, a pixel is a rectangular picture element in an image array, while resolution element is a rectangular area of the surface of the object corresponding to a single pixel.

The device utilized to heat the object surface should be capable of heating the surface to a sufficient temperature to allow thermographic monitoring. Typically, thin objects, e.g. a thickness of about 0.125 inches (0.57 mm) or less, only require minimal heating, about 5° C. or less, with as little as about 1° C. possible. Meanwhile, thick objects may require significantly greater heating, e.g. about 20° C. for a 0.5 inch thick object. The surface factors, including color and emissivity, are also important in determining the degree to heat the object, while the physical properties establish the upper heating limit at a temperature which will not damage the object and/or the object's surface.

In order to accurately locate and determine the size of a flaw, the object surface should be heated to the desired temperature in a sufficiently short period of time so as to inhibit heating of the remainder of the object. Typically heating occurs in a fraction of a second for thin materials with up to a few minutes for thicker or larger materials; in a flash. If the heat penetrates the object, the accuracy of flaw detection near the object surface decreases. For example, a 0.125 thick graphite fiber and polymer composite can be heated for a few milliseconds with a 4 megawatt heat pulse from a flashlamp, while a 0.5 inch thick object should be heated for several seconds or even minutes with a 2 kilowatt heat pulse from a quartz lamp. Other possible heating methods include the use of microwaves, lasers, and other conventional heating means capable of high temperature, high speed heating.

Once the object's surface is heated, an infrared video camera records and stores successive thermal images of the objects surface, recording each pixel thereof. The number of images recorded depends upon the desired resolution of the resulting thermal image, the speed of the camera, and the time constant for the particular object (see below). About 10 images can be used to establish a thermal image, while about 25 images typically provides adequate resolution, and about 100 images establishes good resolution of the thermal image. Generally, up to about 500 images can be obtained at the current state of video technology, with above about 25 preferred.

When the heating device and video camera are located on the same side of the object, the time constant, τ_c, used to establish the period of time for taking the thermal images, is obtained from Equation 1, where the depth is the thickness of the object.

$$\tau_c = \frac{4\, l^2}{\pi^2 \kappa} \tag{1}$$

τ_c = "characteristic" time constant
κ = thermal diffusivity for the object
l = depth

When the camera and the heater are located on opposite sides of the object, the factor of 4 is dropped from Equation 1. Since thermal equilibrium is achieved within an object after approximately 5 characteristic time constants, the period of time used to take the thermal images is typically equivalent to about 3 to about 5 time constants, τ_c, or more.

The video device is preferably a high speed focal plane array camera, or similar device, with a frame rate of at least about 60 flames per second up to about 250 frames per

second or greater and a camera temperature sensitivity of at least about 0.01° C. to about 0.02° C. The minimal acceptable resolution is dependent upon the desired resolution of the final image print, with a resolution of 128×128 or greater pixels typically preferred.

The stored thermal images are used to determine each pixel's contrast by subtracting the mean pixel intensity for that image (point in time) (b) from the individual pixel's intensity (a) at that point in time. The contrast is then plotted versus time for each pixel. (see FIG. 2) The contrast over the flaw site peaks at a time which corresponds to when the image was taken by the video camera, the image number. Given the time at which a peak occurs, the depth of the flaw can be determined; a depth approximation is given by Equation 2:

$$l = \sqrt{\frac{\kappa \tau_{peak}}{3}} \tag{2}$$

l = depth
τ_c = the "characteristic" time constant
k = the "thermal diffusivity" of the medium measured in cgs units of cm^2/sec.

Equation 2 is particularly useful where the flaw's thickness does not force the heat to flow around the flaw; a "through heat" flaw (see FIG. 3A, a "through heat" flaw versus FIG. 3B, a "lateral heat" flaw).

Where, however, the rate of diffusion of the heat is faster around the flaw than through the flaw (FIG. 3B), the contrast peak is not evident from the graph of the pixel contrast (FIG. 4). Consequently, the time derivative of the contrast curve is taken in order to determine the derivative contrast peak. Depth of the "lateral heat" flaw can be determined from the peak time using the following Equation 3:

$$l = 0.524\pi \sqrt{\kappa \tau_i} \tag{3}$$

where

$$\tau_e = 1.10\tau_i \tag{4}$$

l = depth
τ_c = "characteristic" time constant
τ_i = the time of the derivative peak inflection
k = the "thermal diffusivity" of the medium measured in cgs units of cm^2/sec.

EXAMPLE

The accuracy of the present invention was established using an object having a series of carefully placed flat flaws. Referring to FIGS. 6, 6A, 6B, and 6C, flaws 1, 2, 3, 4, and 5 had the same diameter, 22 millimeters (mm), with varying depths, 1.3 mm, 1.6 mm, 1.9 mm, 2.2 mm, and 2.5 mm, respectively. Flaws 6, 7, 8, 9, 10 and 11 had the same depth, 1.3 mm, with varying diameters 22 mm, 16.5 mm, 11 mm, 8.25 mm, 5.5 mm, and 2.75 mm, respectively. Flaws 12, 13, and 14 had the same diameter, 33 mm, with varying depth, 1.3 mm, 1.9 mm, and 2.5 mm, respectively.

The test parameters were as follows: (1) each image frame consisted of N×N pixels (which corresponds to a resolution element on the object surface) where N was 256; (2) the number of image frames, Z, which typically ranges from 1 to 400 for N=128, and 1 to 200 for N=256, was 100; (3) each pixel occupied 2 bytes of storage and was represented by a 12-bit number from 0 to 4095, which represents the thermal radiation intensity.

The object was heated about 5° C. with a 4 megawatt heat pulse from a flashlamp for 0.010 seconds. Once heated, each

resolution element intensity was recorded using a high speed focal plane array camera with a 256×256 pixel resolution operated for about 25 seconds, with each pixel represented by 12 bits. User parameters were determined and entered into the system, including: starting frame number to use for analysis (frame taken before the surface is heated are omitted); squelch constant; noise suppression (discards pixel locations whose absolute value of the peak minus the start or end value of the contrast curve is less than this constant); field of view (distance from the infrared camera to the object; allows scaling and therefore accurate size determination). The contrast of each pixel was determined with respect to the mean pixel intensity for the entire image using the difference between the pixel and the pixel mean times a fixed contrast gain. This operation was performed for each pixel on each image frame, producing a set of contrast curves. The derivative of each contrast curve was then determined using a 6-point difference method. Derivative contrast peak information was stored by saving the image frame number which produced the peak for each derivative contrast curve, or suppressing this information for pixel locations that exhibited low contrast or noise. The image frame location where the derivative contrast peak occurred was then used to determine the depth of the flaws which was shown visually using an intensity color spectrum as shown in FIG. 7. Note, the numbering of flaws shown in FIGS. 7, 8, and 9 is consistent with the number set forth in FIG. 6 which reveals the flaws detected in FIGS. 7, 8, and 9.

The image print of the flaws was produced by assigning the stored peak frame numbers for each pixel to one of the colors in the 16 color palette shown on the right side of FIGS. 7, 8, and 9. This was done by taking the total number of colors (16) divided by the total number of frames (100) and then multiplying this by the peak frame number for the given pixel. This number was then rounded to an integer index into the color palette which selects one of the 16 possible colors for displaying this pixel. This process is then repeated for all of the pixel locations in the image. The image is further enhanced by using 4 intensity levels for each color, shown going from left to right on the color palette in FIGS. 7, 8 and 9. The largest peaks correspond to the highest intensity (level 1) of a given color and the smallest peaks correspond to the lowest intensity (level 4) of a given color. (see FIGS. 7, 8 and 9)

FIG. 8, in contrast, is an image print from the present invention depicting a prior art imaging technique which relies upon a snap-shot of the intensity profile. As is clear from this FIG. 8, the "snap-shot" was taken at a good point in time since all of the flaws are revealed. However, the majority of the flaws appear to be located at the same depth. Consequently, one can not determine the actual depth of any of the flaws. Furthermore, flaw 11 is only barely visible and difficult to identify as a flaw.

FIG. 9, which is also an image print using prior art transient thermography, similarly provides confusing information. In this figure the edges of the flaws appear shallower than the center of the flaws. Consequently, although the flaws are flat, they appear concave. Again, the depth of the flaws cannot be accurately determined.

The present invention provides numerous advantages over prior art non-destructive testing including: virtually eliminating human error, providing the ability to locate a flaw, and simplifying the image. The conventional prior art process relied upon an operator viewing numerous images or relied upon a single "snap shot" of the surface, i.e. human error, merely detected the existence of a flaw. The present invention allows for the accurate determination flaw depth and size, whereas the prior art could not resolve depth accurately.

We claim:

1. A method for detecting flaws in an object having a surface, said surface divided into an array of resolution elements, comprising the steps of:

a. heating the surface of the object;

b. recording a plurality of thermal images of each resolution element on said heated surface over a period of time, wherein each of said recorded resolution elements corresponds to a pixel;

c. determining individual pixel intensity for each of said pixels in each of said thermal images;

d. determining mean pixel intensity for each thermal image;

e. obtaining pixel contrast for each of said pixels in each of said thermal images subtracting said mean pixel intensity from said individual pixel's intensity; and

d. determining depth of the flaw within the object based upon said pixel contrast.

2. A method as in claim 1 wherein the depth of the flaw is determined using the pixel contrast, obtaining the contrast peak, and thereby determining the location of the flaw using the following formula:

$$l=\sqrt{\frac{\kappa\tau_{peak}}{3}}$$

wherein τ_{peak} is the peak time, l is the depth of the flaw, and κ is the thermal diffusivity of the object.

3. A method as in claim 1 wherein the depth of the flaw is determined by calculating the time derivative of the pixel contrast and obtaining the derivative contrast peak.

4. A method as in claim 3 wherein the depth of the flaw is determined by using the following formula:

$$l=\frac{\pi}{2}\sqrt{\kappa\tau_c}$$

wherein τ_c is the characteristic time constant, l is the depth of the flaw, and κ is the thermal diffusivity of the object.

5. A method as in claim 3 wherein the depth of the flaw is determined by using the following formula:

$$l=\pi\sqrt{\kappa\tau_c}$$

wherein τ_c is the characteristic time constant, l is the depth of the flaw, and κ is the thermal diffusivity of the object.

6. A method as in claim 1 further comprising producing an image print of the object which uses a color spectrum to display the depth and lateral position of the flaw.

7. An apparatus for locating flaws in an object having a surface which can be visualized as an array of pixels, comprising:

a. a heater for heating the surface of the object;

b. a recorder for recording pixel intensity;

c. a means for determining pixel contrast from said pixel intensity; and

d. a means for determining depth and location of flaws within the object based upon said pixel contrast.

8. An apparatus as in claim 7 wherein said heater is a flash lamp, quartz lamp, microwave device, or laser.

9. An apparatus as in claim 7 wherein the depth of each flaw is determined from said pixel contrast using the following formula:

$$l=\sqrt{\frac{\kappa\tau_{peak}}{3}}$$

wherein τ_{peak} is the peak time, l is the depth of the flaw, and κ is the thermal diffusivity of the object.

10. An apparatus as in claim 7 wherein the depth of each flaw is determined from a derivative of said pixel contrast using the following formula:

$$l=\frac{\pi}{2}\sqrt{\kappa\tau_c}$$

wherein τ_c is the characteristic time constant, l is the depth of the flaw, and κ is the thermal diffusivity of the object.

11. An apparatus as in claim 7 wherein the depth of each flaw is determined from a derivative of said pixel contrast using the following formula:

$$l=\pi\sqrt{\kappa\tau_c}$$

wherein τ_c is the characteristic time constant, l is the depth of the flaw, and κ is the thermal diffusivity of the object.

12. An apparatus as in claim 7 further comprising a means for forming an image print which displays the depth and lateral position of the flaws using a color spectrum.

13. An object flaw display, said object having a surface, said surface represented by a plurality of resolution elements, comprising:

a. a color spectrum, wherein said spectrum correlates to depth;

b. a means for determining flaw depth below each resolution element of said object surface; and

c. a means for displaying the object surface with the flaws depicted by the color which correlates to the flaw's depth.

14. A method as in claim 13 wherein said means for displaying displays the flaws on an image print.

* * * * *